# POLISHING METHOD AND APPARATUS

## BACKGROUND OF THE INVENTION

Field of the Invention:

The present invention relates to a polishing tool for use in a polishing apparatus for polishing a workpiece such as a semiconductor wafer to a flat mirror finish, and more particularly to a polishing tool such as a fixed abrasive polishing tool or a polishing pad and a method of manufacturing such a polishing tool.

Description of the Related Art:

As semiconductor devices have become more highly integrated in recent years, circuit interconnections have become finer and dimensions of devices to be integrated have become smaller. From this point of view, it may be necessary to polish and planarize a surface of a semiconductor wafer to remove a film (layer) formed on the surface of the semiconductor wafer. In order to planarize a surface of a semiconductor wafer, a polishing apparatus for performing chemical mechanical polishing (CMP) has been used. This type of chemical mechanical polishing (CMP) apparatus comprises a polishing table having a polishing pad (polishing cloth) attached thereon, and a top ring for holding a workpiece to be polished, such as a semiconductor wafer. The workpiece is disposed between the polishing pad and the top ring, and pressed against the polishing pad under a certain pressure by the top ring while the polishing table and the top ring are rotated. In this state, the workpiece is polished to a flat mirror finish while a polishing liquid (slurry) is supplied onto the polishing

pad.

In a chemical mechanical polishing process which employs such polishing liquid (slurry), a workpiece is polished while the polishing liquid (slurry) containing a large amount of abrasive particles is supplied onto a relatively soft polishing pad. Therefore, a problem of pattern dependence arises. Pattern dependence means that gentle irregularities are formed on a surface of a semiconductor wafer after a polishing process due to irregularities on the surface of the semiconductor wafer that existed before the polishing process, thus making it difficult to planarize the surface of the semiconductor wafer to a completely flat surface. Specifically, a polishing rate is higher in an area where irregularities have small pitches (a density of irregularities is large) and is lower in an area where irregularities have large pitches (a density of irregularities is small). Existence of areas of the higher polishing rate and areas of the lower polishing rate causes gentle irregularities to be formed on the surface of the semiconductor wafer.

In order to solve the above problems, it has been proposed to polish a semiconductor wafer with use of a fixed abrasive (grindstone). In such a process, a surface of a semiconductor wafer or the like is polished with a fixed abrasive which comprises abrasive particles fixed by a resin as a binder. With a process utilizing a fixed abrasive which essentially has a large hardness, it is possible to achieve a considerably higher level of planarity. On the other hand, with the process utilizing the fixed abrasive, scratches or defects tend to be produced on a surface of a semiconductor wafer being polished. Thus, it has been proposed

in recent years to polish a semiconductor wafer with a fixed abrasive at a temperature equal to or higher than the glass transition temperature of the binder resin used in the fixed abrasive. However, when a semiconductor wafer is polished by the fixed abrasive at a temperature equal to or higher than the glass transition temperature, the binder resin is softened and tends to be attached to the semiconductor wafer. Once the binder resin is attached to the semiconductor wafer, the binder resin cannot easily be cleaned away.

The fixed abrasive polishing tool is typically manufactured as follows: Abrasive particles and a resin are dispersed in a liquid, and the dispersion is dried to form a mixed powder, and the mixed powder is then compressed and heated to mold a fixed abrasive. If the grain boundary produced when the dispersion is dried to form the mixed powder remains after molding or forming, then the grain boundary is liable to cause scratches to be produced on the semiconductor wafer that is being polished by the fixed abrasive. The same phenomenon tends to occur with not only the fixed abrasive, but also the polishing pad.

## SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a polishing apparatus and method for reducing defects such as scratches or resin deposits on a surface of a workpiece, being polished, such as a semiconductor wafer, and performing a better polishing action on various workpieces to be polished.

Another object is to provide a method of manufacturing a polishing tool for use in such polishing apparatus and method.

According to a first aspect of the present invention, there is provided a polishing method for polishing a workpiece, comprising: pressing a workpiece against a polishing surface of a polishing tool containing a resin to bring the workpiece into sliding contact with the polishing tool, thereby polishing the workpiece with abrasive particles; wherein at least a part of the polishing tool is kept at a temperature equal to or lower than a glass transition temperature of the polishing tool.

According to another aspect of the present invention, there is provided a polishing method for polishing a workpiece, comprising: pressing a workpiece against a polishing surface of a polishing tool containing a resin to bring the workpiece into sliding contact with the polishing tool, thereby polishing the workpiece with abrasive particles; wherein a processing circumstance is kept at a temperature equal to or lower than a glass transition temperature of the polishing tool. The processing circumstance is defined as a processing point or area (polishing surface), and a medium or a member located around the processing point or area. For example, in the case where the processing point or area is the polishing surface, the medium or the member located around the processing point or area is a polishing liquid, a dressing liquid, a workpiece such as a semiconductor wafer, a dresser, or a processing assistance member.

According to a second aspect of the present invention, there is provided a polishing apparatus for polishing a workpiece, comprising: a polishing tool containing a resin; a holder for holding and pressing a workpiece against the polishing tool to bring the workpiece into sliding contact with the polishing tool,

thereby polishing the workpiece with abrasive particles; a temperature regulating device for keeping the polishing tool at a temperature equal to or lower than a glass transition temperature of the polishing tool.

According to the present invention, the polishing tool is used to polish the workpiece at the temperature equal to or lower than the glass transition temperature of the polishing tool, and hence the resin used as a binder resin is prevented from being softened. Therefore, the yield is prevented from being lowered by resin deposits which would otherwise occur on the workpiece due to the softened resin.

In a preferred aspect of the present invention, the polishing surface of the polishing tool is kept at the temperature equal to or lower than the glass transition temperature of the polishing tool.

In a preferred aspect of the present invention, a table or a base plate on which the polishing tool is mounted is cooled to cool the polishing tool or regulate the temperature of the polishing tool to the temperature equal to or lower than the glass transition temperature of the polishing tool.

In a preferred aspect of the present invention, a polishing liquid having a temperature equal to or lower than the glass transition temperature of the polishing tool is supplied to the polishing surface while the workpiece is being polished.

In a preferred aspect of the present invention, the polishing liquid comprises cold water or a chemical liquid.

In a preferred aspect of the present invention, a dressing liquid having a temperature equal to or lower than the glass

transition temperature of the polishing tool is supplied to the polishing surface while the polishing surface is being dressed.

In a preferred aspect of the present invention, a surface of the workpiece being polished is cooled to cool the surface of the workpiece or to regulate the temperature of the surface of the workpiece, thereby cooling the polishing tool or regulating the temperature of the polishing tool to the temperature equal to or lower than the glass transition temperature of the polishing tool.

In a preferred aspect of the present invention, the method further comprises holding a processing assistance member in contact with the polishing surface; and cooling the processing assistance member or regulating the temperature of the processing assistance member to keep the polishing tool at the temperature equal to or lower than the glass transition temperature of the polishing tool.

In a preferred aspect of the present invention, the processing assistance member comprises a dresser for dressing the polishing tool or a member attached to the dresser, the dresser or the member being held in contact with the polishing tool.

In a preferred aspect of the present invention, the processing assistance member is operable independently of the dresser and a holder for holding the workpiece, and the processing assistance member is held in contact with the polishing tool.

In a preferred aspect of the present invention, the processing assistance member is attached to a holder for holding the workpiece and held in contact with the polishing tool.

According to a third aspect of the present invention, there

is provided a method of manufacturing a polishing tool, comprising: drying a mixed liquid including a resin and chemical agents to form a dried solid material; and compressing and forming the dried solid material with heat into a polishing tool; wherein the drying temperature is lower than the temperature of the compressing and forming.

According to a fourth aspect of the present invention, there is provided a method of manufacturing a polishing tool, comprising: drying a mixed liquid including a resin and chemical agents to form a dried solid material; and compressing and forming the dried solid material with heat into a polishing tool; wherein the temperature of the compressing and forming is higher than a glass transition temperature of the resin or a dissolution temperature of the resin.

According to a fifth aspect of the present invention, there is provided a method of manufacturing a polishing tool, comprising: drying a mixed liquid including a resin and chemical agents to form a dried solid material; and compressing and forming the dried solid material with heat into a polishing tool; wherein a resin solvent is added to the mixed liquid.

According to a sixth aspect of the present invention, there is provided a method of manufacturing a polishing tool, comprising: drying a mixed liquid including a resin and chemical agents to form a dried solid material; and compressing and forming the dried solid material with heat into a polishing tool; wherein an organic solvent or a foaming agent is added to the dried solid material.

According to the present invention, a grain boundary is

prevented from being developed in the dried solid material when the mixed liquid is dried with heat, and is prevented from being left in the polishing tool after compressing and forming the dried solid material with heat. Consequently, a workpiece which is polished by the polishing tool is prevented from being scratched by a grain boundary which would otherwise be developed in the polishing tool when the mixed liquid is dried into the dried solid material.

In a preferred aspect of the present invention, the mixed liquid includes abrasive particles.

The above and other objects, features, and advantages of the present invention will become apparent from the following description when taken in conjunction with the accompanying drawings which illustrate preferred embodiments of the present invention by way of example.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of a polishing apparatus according to an embodiment of the present invention;

FIG. 2 is a cross-sectional view of a modification of the polishing apparatus shown in FIG. 1;

FIG. 3 is a view, partly in block form, of a cooling or temperature regulating apparatus;

FIG. 4 is a view, partly in block form, of a modification of the cooling or temperature regulating apparatus shown in FIG. 3;

FIG. 5 is a vertical cross-sectional view of a wafer carrier (top ring) in the polishing apparatus according to an embodiment

of the present invention;

FIG. 6 is a vertical cross-sectional view of a dresser in the polishing apparatus according to an embodiment of the present invention;

FIG. 7A is a vertical cross-sectional view of a general ring-type dresser;

FIGS. 7B, 7C and 7D are vertical cross-sectional views of various dressers which have a cooling (temperature regulating) function, respectively;

FIGS. 8A and 8B are plan views showing a contact member for regulating the temperature of a polishing tool that is provided independently of a wafer carrier (wafer holder) and a dresser;

FIG. 8C is a vertical cross-sectional view of the contact member;

FIG. 9 is a flowchart of a method of manufacturing a polishing tool according to an embodiment of the present invention;

FIG. 10 is a schematic diagram showing an ultrasonic dispersing process for ultrasonically dispersing a mixed liquid;

FIG. 11 is a schematic diagram showing a process of forming a granulated powder with a spray drier;

FIGS. 12A through 12C are cross-sectional views showing a process of heating and compressing a forming material (granulated powder) to form a compact;

FIGS. 13A and 13B are perspective views of completed fixed abrasive polishing tools; and

FIGS. 14A through 14E are cross-sectional views showing the manner in which a fixed abrasive polishing tool containing a chemical agent (water-absorbing resin) operates.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A polishing tool and a polishing apparatus incorporating the polishing tool according to embodiments of the present invention will be described below.

First, a glass transition temperature (Tg) will be described below. When a thermoplastic macromolecure (linear macromolecule) is heated, the linear macromolecule starts thermal motion at a certain temperature, thus changing into a rubber-like state in its entirety. The certain temperature referred to the above is defined as a glass transition temperature. At the glass transition temperature, the linear macromolecure changes from a hard brittle state such as a glass-like state to a pliable state. Some resins exhibit fluidity when they are heated to a temperature equal to or higher than the glass transition temperature (Tg). The melting temperature (dissolution temperature) of macromolecule is generally referred to as a melting point (Tm). The dissolution temperatures of macromolecules are sometimes not definite, and hence need to be distinguished from general melting temperatures. Furthermore, some resins are not melted, but are pyrolyzed or cured. Specifically, a thermoplastic resin, in particular a formed resin (a resin formed of linear macromolecule), has linear macromolecules intertwined into a solid, like a nonwoven fabric. At temperatures below the glass transition temperature (Tg), the linear macromolecules remain firmly intertwined. Even if external forces are applied to the linear macromolecule at those temperatures, the intertwined structure may be deformed, but is prevented from being disentangled.

Therefore, the linear macromolecule is generally highly resistant to external forces. In environments higher than the glass transition temperature (Tg), but lower than temperatures at which linear macromolecules are dissolved, melted, pyrolyzed, or cured, the intersection points where the molecules are intertwined are liable to move.

In a polishing process in which a workpiece such as a semiconductor wafer is pressed against and brought in sliding contact with a polishing tool composed mainly of a thermoplastic resin, thereby polishing the workpiece with abrasive particles, when the workpiece is polished at a temperature higher than the dissolution temperature of the thermoplastic resin, the polishing tool becomes soft and is less likely to produce scratches on the surface of the workpiece. However, the thermoplastic resin is dissolved and easily attached to the surface of the workpiece being polished. When the workpiece is polished at a temperature higher than the glass transition temperature, the thermoplastic resin changes from a solid state to a viscous state and is easily attached to the surface of the workpiece being polished. If such a thermoplastic resin is actually attached to the polished surface of a semiconductor wafer, then the thermoplastic resin deposit may be dissolved by sulfuric acid with oxygenated water added, hydrochloric acid (35 %aq), or an organic solvent such as acetone or the like, or the outermost surface of the polished wafer may be dissolved by DHF or the like to cause the thermoplastic resin deposit to be removed away. At any rate, a new cleaning process needs to be added, making it difficult to deal with the thermoplastic resin deposit within a short period of time.

According to the present invention, in a process in which a workpiece such as a semiconductor wafer is pressed against and brought in contact with a polishing tool containing a resin, thereby polishing the workpiece with abrasive particles, the processing circumstance is kept at a temperature equal to or lower than a glass transition temperature (Tg) of the polishing tool.

By keeping the processing temperature at a melting point (Tm) or less, and a glass transition temperature (Tg) or less, the resin is in a glass state to prevent itself from being attached to a surface of the workpiece being polished. Preferably, the glass transition temperature (Tg) of the resin should be equal to or higher than the ordinary temperature for the purpose of handling the polishing tool. If the glass transition temperature (Tg) of the resin were lower than the ordinary temperature, the resin would tend to become soft, making it difficult to handle the polishing tool. If an aqueous polishing liquid is used in the polishing process, because the polishing liquid is frozen at nearly 0°C, the range of temperatures in which the polishing liquid can be used is narrow.

The resin to be used may be prepared by mixing or polymerizing various resins. The resins should have an average glass transition temperature (Tg) equal to or higher than the ordinary temperature, and the polishing tool should be used during a polishing process at a temperature equal to or lower than the average glass transition temperature (Tg). More preferably, among resin materials or constituent resins, the glass transition temperature (Tg) of resin component having the lowest glass transition temperature should be equal to or higher than the

ordinary temperature, thereby effectively reducing the attachment of the resin to the surface being polished.

As a method for controlling the temperature of a polishing tool during a polishing process, there are a method in which the temperature of the polishing tool is regulated by cooling the reverse side of the polishing tool or regulating the temperature of the reverse side of the polishing tool, and a method in which the temperature of the polishing tool is regulated by cooling the polishing surface or regulating the temperature of the polishing surface. As a method for cooling a polishing surface or regulating the temperature of a polishing surface, there are a method for applying cooling air to the polishing surface, a method for using a polishing liquid which can be easily evaporated, a method for utilizing evaporation heat generated when a polishing liquid is evaporated by, for example, spraying the polishing liquid, and a method for performing a heat exchange with a member which is brought in direct contact with the polishing surface.

As a means or device for cooling a polishing tool or regulating the temperature of the polishing tool to a temperature equal to or lower than the glass transition temperature (Tg) of the polishing tool, a means or device for cooling a table or a base plate or regulating the temperature of the table or the base plate as shown in FIG. 1 can be employed.

As shown in FIG. 1, in a polishing apparatus 100, a semiconductor wafer W, which is a workpiece to be polished, is pressed against and brought in sliding contact with a polishing tool 10, and is polished with abrasive particles. The polishing tool 10 is mainly composed of a thermoplastic resin. The polishing

tool 10 is fixedly mounted on a turntable 50 through a base plate 20, and is rotatable by the turntable 50 about an axis of a main shaft coupled to the turntable 50. The semiconductor wafer W is supported on a top ring 110 and is rotatable by the top ring 110 about an axis of a main shaft coupled to the top ring 110. The top ring 110 constitutes a wafer carrier or a wafer holder. The semiconductor wafer W supported on the top ring 110 is pressed against and brought in sliding contact with the polishing surface of the rotating polishing tool 10, and hence the semiconductor wafer W is progressively polished. At this time, the polishing surface of the polishing tool 10 is supplied with a polishing liquid containing a large amount of abrasive particles from a nozzle 130. The polishing apparatus 100 also has a dresser 120 having a dressing surface 121. The dressing surface is pressed against and brought in sliding contact with the polishing surface of the polishing tool 10, thereby dressing the polishing surface. Another nozzle 123 is provided to supply a dressing liquid such as pure water or the like to the polishing surface of the polishing tool 10.

The polishing apparatus 100 has a cooling device (pipe) 60 disposed in the turntable 50 for cooling the turntable 50 and the base plate 20. The cooling device (pipe) 60 is supplied with a circulating cooling liquid which is regulated to a predetermined temperature. The cooling device (pipe) 60 can cool the polishing tool 10 or regulate the temperature of the polishing tool 10 to a temperature equal to or lower than the glass transition temperature (Tg) of the thermoplastic resin of the polishing tool 10.

It is generally known that the temperature of the polishing surface of the polishing tool increases during a polishing process, and that the turntable of a general CMP apparatus is often provided with a water-cooled cooling unit. However, the temperature of the cooling unit often depends on the temperature of water which is supplied from a public water supply system to the cooling unit. The temperature of water which is supplied from the public water supply system is required to be kept in a temperature range equal to or lower than the glass transition temperature (Tg). If water supplied from the public water supply system fails to sufficiently cool the turntable, then it is necessary to add a cooling device for cooling the turntable so that the processing temperature is controlled so as to be equal to or lower than the melting temperature (Tm) and also the glass transition temperature (Tg). In this case, the polishing tool is cooled or the temperature of the polishing tool is regulated from the reverse side of the polishing surface of the polishing tool, making it possible to cool the polishing tool sufficiently. If the polishing tool comprises a fixed abrasive, then the polishing tool which is cooled by the cooling device is sufficiently hard in its lower layer to thus provide highly flat polishing characteristics. Since the resin of the polishing tool is generally of low thermal conductivity and tends to accumulate heat easily, the polishing tool should have a thickness of 5 mm or less in order to cool the polishing surface thereof to a temperature equal to or lower than the glass transition temperature (Tg).

According to the present invention, in a process in which a workpiece is polished with abrasive particles by being pressed

against and brought in sliding contact with a polishing tool containing a resin, the polishing tool can be kept at a temperature equal to or lower than the glass transition temperature (Tg) of the resin by supplying a polishing liquid, or a dressing liquid such as water (cold water) or a chemical liquid having a temperature equal to or lower than the glass transition temperature of the resin onto the polishing tool during processing. There are two cases for supplying a polishing liquid, or a dressing liquid. In the first case, polishing of the workpiece is not carried out during dressing, and hence only a dressing liquid is supplied to a polishing tool. Because polishing of the workpiece is not carried out, dressing of the polishing tool can be carried out without regulating the temperature of the dressing liquid. However, by supplying the dressing liquid which is cooled or regulated in temperature, the polishing surface of the fixed abrasive polishing tool can be prevented from being degraded or deteriorated. Thereafter, only a polishing liquid is supplied to the polishing tool during polishing, and hence the resin used as a binder resin is prevented from being softened and attached to the workpiece only by supplying the polishing liquid which is cooled or regulated in temperature. In the second case, the temperature of the polishing liquid is regulated during polishing, and when required, the dressing liquid is supplied during polishing. In this case, the polishing liquid and the dressing liquid are separately supplied to the polishing surface, and hence both of the polishing liquid and the dressing liquid are required to be cooled or regulated in temperature. In order to keep the polishing surface of the polishing tool at a desired temperature,

the polishing surface should preferably be cooled directly. Therefore, a member for directly contacting the polishing surface may be used for performing a heat exchange with the polishing surface during processing. The outermost surface of the polishing tool can be controlled at a temperature equal to or lower than the glass transition temperature (Tg) of the resin by cooling the polishing liquid or the dressing liquid, or regulating the temperature of the polishing liquid or the dressing liquid.

According to the present invention, in a process in which a workpiece is polished with abrasive particles by being pressed against and brought in sliding contact with a polishing tool containing a resin, in order to cool the surface of the workpiece being polished or regulate the temperature of the surface of the workpiece being polished so that the workpiece is kept at a temperature equal to or lower than the glass transition temperature (Tg) of the resin, a polishing liquid whose temperature is controlled to a predetermined temperature is supplied from a nozzle 130 to the polishing tool 10, or a dressing liquid whose temperature is controlled to a predetermined temperature is supplied from a nozzle 123 to the polishing tool 10 as shown in FIG. 2. Thus, the polishing surface of the polishing tool 10 can be controlled at a temperature equal to or lower than the glass transition temperature (Tg) of the resin. Preferably, each of the nozzles 123, 130 is covered with a heat insulation 135 and has its tip end combined with a temperature sensor 140, thereby controlling each of the nozzles 123, 130 at a predetermined temperature. As shown in FIG. 3 or FIG. 4, the polishing liquid

supplied to the nozzle 130 or the dressing liquid supplied to the nozzle 123 can be cooled, or the temperature of the polishing liquid supplied to the nozzle 130 or the dressing liquid supplied to the nozzle 123 can be regulated, by a heat exchanger.

As shown in FIG. 3, a polishing liquid or a dressing liquid stored in a supply tank 71 is delivered through a supply line 72 by a pump 73 to the nozzle 130 or 123 (see FIG. 2). A container 74 is provided to store a liquid such as water which is cooled by a coil 75a of a heat exchanger 75. A part of the supply line 72 is cooled by the liquid stored in the container 74. Thus, the polishing liquid or the dressing liquid is cooled by the heat exchanger 75 to a predetermined temperature before it reaches the nozzle 130 or 123.

As shown in FIG. 4, a polishing liquid or a dressing liquid stored in a supply tank 71 is delivered through a supply line 72 by a pump 73 to the nozzle 130 or 123 (see FIG. 2). A heat exchanger 76 is provided so as to enclose a part of the supply line 72. Thus, the polishing liquid or the dressing liquid flowing through the supply line 72 is cooled by the heat exchanger 76 to a predetermined temperature before it reaches the nozzle 130 or 123.

FIG. 5 shows a top ring (wafer carrier or wafer holder) 110 for holding a semiconductor wafer W. The top ring 110 has a cooling pipe (temperature regulating pipe) 150 disposed therein, and a cooling liquid (temperature regulating liquid) 152 is supplied to the cooling pipe (temperature regulating pipe) 150 through a rotary joint 151. The polishing tool 10 (see FIG. 1 or 2) can be cooled or the temperature of the polishing tool 10

can be regulated to a temperature equal to or lower than the glass transition temperature (Tg) of the polishing tool 10 by the cooling liquid (temperature regulating liquid) 152 supplied via the cooling pipe (temperature regulating pipe) 150 through the semiconductor wafer W which is held against the polishing surface of the polishing tool 10. If the semiconductor wafer W is locally cooled or the temperature of the semiconductor wafer W is locally regulated by the cooling liquid (temperature regulating liquid) 152, then the semiconductor wafer W tends to be deformed due to difference in thermal expansion. Therefore, the cooling pipe (temperature regulating pipe) 150 should preferably be arranged in the top ring 110 so that the entirety of the top ring 110 is cooled or the temperature of the entirety of the top ring 110 is regulated.

FIG. 6 shows a dresser 120 combined with a cooling pipe (temperature regulating pipe) 153 for cooling the polishing surface of the polishing tool 10. Specifically, the cooling pipe (temperature regulating pipe) 153 is disposed in the dresser 120 and is supplied with a cooling liquid (temperature regulating liquid) 155 through a rotary joint 154. When the cooling liquid (temperature regulating liquid) 155 flows through the cooling pipe (temperature regulating pipe) 153, the dresser 120 is cooled or the temperature of the dresser 120 is regulated, whereby the polishing surface of the polishing tool 10 is cooled through the dressing surface 121. In this manner, the polishing surface of the polishing tool 10 can be kept at a temperature equal to or lower than the glass transition temperature (Tg) of the polishing tool 10. In order to prevent the dresser 120 from being deformed

due to difference in thermal expansion, it is preferable to provide the cooling pipe (temperature regulating pipe) 153 in the dresser 120 so as to cool the entirety of the dresser 120 including the dressing surface 121. The cooling liquid (temperature regulating liquid) 155 may comprise water or the like which is cooled or regulated in temperature to a predetermined temperature, and supplied to the cooling pipe (temperature regulating pipe) 153 in an amount sufficiently large for keeping the polishing surface of the polishing tool 10 at a temperature equal to or lower than the glass transition temperature (Tg). The top ring 110 or the dresser 120 may be provided with a temperature sensor so that the top ring 110 or the dresser 120 can be controlled at a predetermined temperature.

According to the present invention, in a process in which a workpiece is polished with abrasive particles by being pressed against and brought in sliding contact with a polishing tool containing a resin, a processing assistance member may be used for contacting the polishing surface of the polishing tool 10 to cool the polishing tool 10 or regulate the temperature of the polishing tool 10 to a temperature equal to or lower than the glass transition temperature (Tg) of the polishing tool during processing. The processing assistance member may comprise a dresser or a member attached to the dresser and held in contact with the polishing tool 10. For example, a polishing tool contact member disposed around the dresser may be cooled, or may be regulated in temperature to cool the polishing tool or regulate the temperature of the polishing tool, thereby keeping the polishing tool at a temperature equal to or lower than the glass

transition temperature (Tg). In this manner, the polishing surface of the polishing tool 10 can be kept in a glass state for thereby reducing resin deposits on the polished surface of the workpiece. The polishing tool contact member disposed around the dresser is also effective to prevent the dresser from being tilted due to wear, thus providing uniform dressing effect of the polishing tool 10.

FIGS. 7A through 7D show various cooling members (temperature regulating members) attached to dressers. FIG. 7A shows a general ring-type dresser, and FIGS. 7B through 7D show various dressers combined with respective contact members for cooling the polishing tool or regulating the temperature of the polishing tool. Specifically, FIG. 7A shows a dresser holder 120 with an annular dresser tool 121 mounted on a lower surface thereof. The dresser holder 120 is supported on the lower end of a main shaft 122 through a ball joint 122a.

FIG. 7B shows a dresser with a retainer temperature regulator. As shown in FIG. 7B, a cooling pipe (temperature regulating pipe) 125 is disposed in a dresser holder 120 and supplied with a cooling liquid (temperature regulating liquid) 127 from a cooling liquid (temperature regulating liquid) supply device (not shown) through a rotary joint 126. An annular retainer 128a made of a high heat transfer material is disposed around an annular dresser tool 121 mounted on the lower surface of the dresser holder 120. The cooling liquid (temperature regulating liquid) 127 flowing through the cooling pipe (temperature regulating pipe) 125 cools the polishing surface of the polishing tool 10 or regulates the temperature of the polishing surface of the polishing tool 10 through the

dresser holder 120. Therefore, the dresser shown in FIG. 7B is capable of cooling the polishing surface of the polishing tool 10 or regulating the temperature of the polishing surface of the polishing tool 10 while dressing the polishing tool 10 with the dresser tool 121. Because the dresser tool 121 is of a ring shape and has a small area of contact with the polishing tool 10, the retainer 128a should preferably comprise a highly flat member having a flatness of 0.1 mm or less. The ring-shaped retainer 128a is effective to stabilize the ring-shaped dresser tool 121 in operation and also to condition the polishing surface of the polishing tool 10 which has been excessively roughened by dressing. The surface of the retainer 128a which is held in contact with the polishing tool 10 may have a radial, concentric, spiral, or grid-like pattern of grooves for draining the waste dressing liquid.

FIG. 7C shows a dresser having a dresser holder 120 combined with a heat accumulator 129. The dresser has a cooling pipe (temperature regulating pipe) 125 disposed in the dresser holder 120 for circulating a cooling liquid (temperature regulating liquid) 127. The heat accumulator 129 accumulates a cold heat, and hence cools the polishing surface of the polishing tool 10 through the dresser tool 121 while the polishing surface is being dressed by the dresser tool 121.

FIG. 7D shows a dresser with an inner circumference temperature regulator. As shown in FIG. 7D, a contact member 128b for cooling the polishing tool 10 or regulating the temperature of the polishing tool 10 is disposed on the lower surface of a dresser holder 120 at a position radially inwardly

of an annular dresser tool 121. The dresser tool 121 is disposed on an outer circumferential region of the dresser holder 120. The contact member 128b made of a high heat transfer material is disposed inwardly of the dresser tool 121. A cooling pipe (temperature regulating pipe) 125 is disposed in the dresser holder 120 and supplied with a cooling liquid (temperature regulating liquid) 127 from a cooling liquid (temperature regulating liquid) supply device (not shown) through a rotary joint 126. Because the contact member 128b is disposed on an inner circumferential region of the dresser holder 120 and the dresser tool 121 is disposed on an outer circumferential region of the dresser holder 120, the waste dressing liquid can be easily drained from the dresser tool 121. Thus, it is not necessary to form a complex pattern of grooves in the surface of the contact member 128b which is held against the polishing surface of the polishing tool 10.

Each of the dressers shown in FIGS. 7A through 7D should preferably be combined with a temperature sensor for feedback of the temperature of the cooling liquid (temperature regulating liquid) to the cooling liquid (temperature regulating liquid) supply device for thereby controlling the temperature of the cooling liquid (temperature regulating liquid) accurately. The temperature sensor may comprise a radiation thermometer, a thermocouple, a resistance temperature sensor, a thermistor, or the like. The temperature sensor may be positioned within the contact member such as a retainer or on the dresser holder.

A processing assistance member for contacting the polishing tool to cool the polishing tool or regulate the temperature of

the polishing tool may be provided independently of a dresser holder having a dresser tool or a top ring for holding a semiconductor wafer. For example, a polishing tool contact member which can be controlled in operation independently of the dresser and the wafer carrier (wafer holder) may be provided for cooling the polishing tool or regulating the temperature of the polishing tool to keep the polishing surface of the polishing tool at a temperature equal to or higher than the glass transition temperature of the polishing tool. Because the resin of the polishing tool is in a glass state during a polishing process, resin deposits on the polishing surface of the semiconductor wafer can be reduced. The polishing tool contact member which can be controlled in operation independently of the dresser and the wafer carrier (wafer holder) can condition the polishing surface of the polishing tool by controlling the contact pressure applied by the polishing tool contact member, thus performing stable dressing. Then, stable polishing of the semiconductor wafer can be performed using the stably dressed polishing tool. The independent polishing tool contact member may be fixed in position or may be angularly moved. The pressure applied by the polishing tool contact member, the angular movement of the polishing tool contact member, and the position fixing of the polishing tool contact member may be controlled to control the amount of material removed from the polishing tool while the polishing tool is being monitored. If the polished configuration of the semiconductor wafer can be predicted, then the pressure applied by the polishing tool contact member, the angular movement of the polishing tool contact member, and the position fixing of the polishing tool

contact member can be selected based on a predicted value.

FIGS. 8A through 8C show polishing apparatuses having an independent contact member that can be operated independently of a dresser and a top ring.

FIG. 8A shows a stationary-type polishing apparatus comprising a top ring 110 for holding a semiconductor wafer W and a dresser 120 for dressing a rotatable polishing tool 10, the top ring 110 and the dresser 120 being fixedly positioned with respect to the polishing tool 10 and being rotatable about their own axes, respectively. The polishing apparatus also has an independent contact member 160 for cooling the polishing tool 10 or regulating the temperature of the polishing tool 10 independently of the top ring 110 and the dresser 120. As shown in FIG. 8C, a cooling pipe (temperature regulating pipe) 164 is disposed in a holder 161, and a cooling liquid (temperature regulating liquid) 165 is supplied from a cooling liquid (temperature regulating liquid) supply device (not shown) to the cooling pipe (temperature regulating pipe) 164 through a main shaft 162 and a rotary joint 163, thereby cooling the entire contact member 160 or regulating the temperature of the entire contact member 160. The contact member 160 is made of a high heat transfer material for transferring a cold heat supplied from the cooling pipe (temperature regulating pipe) 164 to the polishing tool 10, thereby cooling the polishing surface of the polishing tool 10 or regulating the temperature of the polishing surface of the polishing tool 10. Thus, the polishing surface of the polishing tool 10 is kept at a temperature equal to or lower than the glass transition temperature, and hence the resin of the polishing tool

10 is in a glass state, thus reducing resin deposits on the polished surface of the semiconductor wafer W.

FIG. 8B shows a swingable-type polishing apparatus comprising a top ring 110 supported on a swing arm 110a, a dresser 120 supported on a swing arm 120a, and an independent contact member 160 supported on a swing arm 160a. The swing arms 110a, 120a and 160a are swingable, when necessary, with respect to a polishing tool 10. When the swing arm 110a is swung, the top ring 110 is angularly moved with respect to the polishing tool 10 for increasing an area of contact of the semiconductor wafer W with the polishing tool 10. When the swing arm 120a is swung, the dresser 120 is angularly moved with respect to the polishing tool 10 for dressing an increased area of the polishing tool 10. When the swing arm 160a is swung, the independent contact member 160 is angularly moved with respect to the polishing tool 10 for preferentially regulating the temperature of a region of the polishing tool 10 which is more likely to change than that of other regions thereof.

A member for directly contacting the polishing tool may comprise a member attached to the wafer carrier (wafer holder) and held in contact with the polishing tool. For example, a polishing tool contact member such as a retainer ring disposed around the top ring may be cooled, or the temperature of the polishing tool contact member may be regulated to cool the polishing tool or regulate the temperature of the polishing tool.

Materials which can be used to make up the polishing tool will be described in detail below.

Generally, a polishing tool is made up of a resin, pores,

when required, abrasive particles, and chemical agents. The resin should preferably comprise a thermoplastic resin rather than a thermosetting resin. If the polishing tool is a fixed abrasive polishing tool, it contains abrasive particles. Materials for abrasive particles may comprise cerium oxide ($CeO_2$), titanium oxide ($TiO_2$: though titanium oxide is available in rutile and anatase crystalline structures, anatase titanium oxide is preferable as it is more reactive), alumina ($Al_2O_3$), silicon carbide (SiC), silicon oxide ($SiO_2$), zirconia ($ZrO_2$), iron oxide (FeO, $Fe_3O_4$), manganese oxide ($MnO_2$, $Mn_2O_3$), magnesium oxide (MgO), calcium oxide (CaO), barium oxide (BaO), zinc oxide (ZnO), barium carbonate ($BaCO_3$), calcium carbonate ($CaCO_3$), diamond (C), or a composite material thereof. The materials for abrasive particles may be in the form of a powder or a slurry. However, in order to produce a uniform fixed abrasive, it is preferable to use slurry-like abrasive particles in which fine abrasive particles are stably present. More preferably, the polishing tool should contain abrasive particles having a particle diameter of from 10 nm to 10 $\mu$m. Further, in order to produce a polishing tool for processing semiconductor wafers, any metals contained in materials for abrasive particles should be minimized.

Thermosetting resins that can be used in the polishing tool include phenol-formaldehyde resin (PF), urea-formaldehyde resin (UF), melamine-formaldehyde resin (MF), unsaturated polyester resin (UP), epoxy resin (EP), silicone (SI), polyurethane (PUR), etc.

Thermoplastic resins that can be used in the polishing tool include polyvinyl chloride (PVC) known as general-purpose

plastics, polyethylene (PE), polypropylene (PP), polystyrene (PS), acrylonitrile-butadiene-styrene (ABS), acrylonitrile-styrene (AS), polymethylmethacrylate (PMMA), polyvinyl alcohol (PVA), polyvinylidene chloride (PVDC), polyethylene terephthalate (PET), polyamide (PA) known as general-purpose engineering plastics, polyacetal (POM), polycarbonate (PC), polyphenylene ether (PPE) (modified PPO), polybutylene terephthalate (PBT), ultra-high- molecular-weight polyethylene (UHMWPE), polyvinylidene fluoride (PVDF), polysulfone (PSF) known as super engineering plastics, polyethersulfone (PES), polyphenylene sulfide (PPS), polyarylate (PAR), polyamideimide (PAI), polyehterimide (PEI), polyether ether ketone (PEEK), polyimide (PI), and polytetrafluoroethylene (PTFE). Of these resins, ABS and PVDF are particularly effective for removing scratches. Two or more of the above resins may be mixed with each other for use in the polishing tool. Monomers of the above resins may be copolymerized.

If the polishing tool needs to be a soft polishing tool, then preferred resins for use in such soft polishing tool include polyvinyl fluoride, polyvinylidene fluoride, polychlorotrifluoroethylene, vinyl fluoride, vinylidene fluoride, dichlorofluoroethylene, vinyl chloride, vinylidene chloride, perfluoro-α-olefins (for example, hexafluoropropylene, perfluorobutene-1, perfluoropentene-1, perfluorohexene-1, or the like), perfluorobutadiene, chlorotrifluoroethylene, trichloroethylene, tetrafluoroethylene, perfluoroalkyl perfluorovinyl ethers (for example, perfluoromethyl

perfluorovinyl ether, perfluoroethyl perfluorovinyl ether, perfluoropropyl perfluorovinyl ether, or the like), alkyl vinyl ether with the number of carbon atoms ranging from 1 to 6, allyl vinyl ether with the number of carbon atoms ranging from 6 to 8, alkyl with the number of carbon atoms ranging from 1 to 6, allyl perfluorovinyl ether, ethylene, propylene, styrene, or the like with the number of carbon atoms ranging from 6 to 8, polyvinylidene fluoride, polyvinyl fluoride, vinylidene fluoride-tetrafluoroethylene copolymer, vinylidene fluoride-hexafluoropropylene copolymer, tetrafluoroethylene-ethylene copolymer, tetrafluoroethylene-propylene copolymer, ethylene-chlorotrifluoroethylene copolymer, tetrafluoroethylene-chlorotrifluoroethylene copolymer, tetrafluoroethylene-hexafluoropropylene copolymer, tetrafluoroethylene-perfluoromethyl perfluorovinyl ether copolymer, tetrafluoroethylene-perfluoroethyl perfluorovinyl ether copolymer, tetrafluoroethylene-perfluoropropyl perfluorovinyl ether copolymer, tetrafluoroethylene-hexafluoropropylene-perfluoromethyl perfluorovinyl ether copolymer, tetrafluoroethylene-hexafluoropropylene-perfluoroethyl perfluorovinyl ether copolymer, tetrafluoroethylene-hexafluoropropylene-perfluoro propyl perfluorovinyl ether copolymer, etc.

Of the above resins, from the standpoints of foaming properties, economy, and availability, preferable resins are polyvinylidene fluoride, polychlorotrifluoroethylene,

vinylidene fluoride-hexafluoropropylene copolymer, ethylene-tetrafluoroethylene copolymer, ethylene-chlorotrifluoroethylene copolymer, tetrafluoroethylene-perfluoroalkyl perfluorovinylether copolymers, and tetrafluoroethylene-hexafluoropropylene copolymer. More preferable are polyvinylidene fluoride and vinylidene fluoride-hexafluoropropylene copolymer as partially fluorocarbon resins, and tetrafluoroethylene-perfluoroalkyl perfluorovinylether copolymers as perfluororesins.

It is preferable to select thermoplastic resins, and the resins should preferably have glass transition temperatures (Tg) equal to or higher than the ordinary temperature.

The polymeric material may be in the form of either a powder or a liquid. In order to uniformize the composition ratio of a granulated powder as a forming material and increase the uniformity of the fixed abrasive, it is preferable to use a latex suspension where the polymeric material is uniformly dispersed in a liquid. For use in semiconductor applications, i.e., for polishing semiconductor wafers with reduced metal contamination, the amount of any metals contained in the polymeric material should be as small as possible. The thermoplastic material is generally manufactured by polymerizing many monomers through different processing stages including addition polymerization, copolymerization, condensation polymerization, addition condensation, etc. In those processing stages, water and various agents including polymerization catalysts represented by organometallic compounds and inorgannometallic compounds, polymerization-retarders, dispersing agents, activators,

solvents, catalyst deactivators, stabilizers, emulsifiers, antioxidants, etc are used. The monomers are processed into the polymeric material through a complex process. In order to reduce the amount of metals introduced into the polymeric material of the polishing tool, it is preferable to reduce the metal compounds contained in the chemical agents and water used in the above various polymerization stages. The water and solvents that are used in the polymerization process should preferably comprise pure water or ultrapure water and highly pure solvents, respectively.

Other suitable additives (agents) may be added other than the polymeric material. These additives (agents) include accelerators ( for example, amine) including micro (nano) capsule agents, stabilizers (buffers), mirror-finish improvers (water-soluble macromolecures), polishing additives such as abrasive particle anticoagulants (organic macromolecures), abrasive particle self-sharpening regulators (binder dissolvers), fixed abrasive forming additives, fixed abrasive processing additives (photosensitizers), etc. The amount of metals contained in these additives should also be as small as possible.

A process of manufacturing a fixed abrasive will be described below.

First, a fixed abrasive material powder is manufactured by mixing fine abrasive particles, a polymeric material, and additives including a dispersing agent such as a surface active agent, a stabilizer such as a buffer, an accelerator represented by a pH adjuster such as KOH, a mirror-finish improver such as a macromolecure agent, etc. The above materials are mixed with

each other, and, if necessary, pure water and a solvent are added to the mixture. The materials are sufficiently dispersed using a stirrer, an ultrasonic dispersing device, or the like.

Then, the mixed liquid is dried by a dryer such as a spray drier into a powder (granulated powder) in which various materials are uniformly mixed. The powder (granulated powder) has a diameter of 0.1 µm to several hundreds µm, preferably an average diameter of several µm to several tens µm. Alternatively, a powder may be produced by freeze-drying and then pulverizing, coagulating, and/or precipitating. In the above powder (granulated powder) producing process, the materials may be mixed and then dried, or dried and then mixed, or repeatedly mixed and dried. Depending on the material to be mixed, a material may be directly mixed with a dried powder of other materials.

Next, suitable additives (the above agents) are added to the mixed powder (granulated powder) obtained by the above process, thus producing a powdery mixture. The powdery mixture is then compressed by a compression forming machine which typically comprises a hot press, thereby producing a fixed abrasive polishing tool. The size of the compression forming machine is determined by the size of the fixed abrasive polishing tool to be produced. Therefore, the size of the compression forming machine may be smaller if the fixed abrasive polishing tool is of a split type, i.e., segment type, than if the fixed abrasive polishing tool is of a non-split type. If a split-type, i.e., segment-type fixed abrasive polishing tool is produced, then associated fabrication equipment and subsequent processing equipment may also be smaller in size. Consequently, initial

investments are smaller, and the manufacturing cost is lower.

In order to facilitate the protection of the fixed abrasive and the installation thereof onto a polishing apparatus, the produced fixed abrasive is fixed to a member (base) having mechanical strength, such as a member made of metal or engineering plastics, by adhesion or deposition. If the fixed abrasive is made up of a number of segments having a complex shape, then the segments are difficult to be positioned when secured to the base. If the segments are positioned inaccurately on the base, then the adhesive applied to secure the fixed abrasive to the base tends to be squeezed into gaps between the segments. If the adhesive is positioned on the polishing surface of the fixed abrasive, then the adhesive is likely to hamper the polishing action or produces scratches on the semiconductor wafer being polished. Therefore, the segments of the fixed abrasive need to be positioned accurately.

Undue gaps between the segments pose a problem in that when the semiconductor wafer is polished by the fixed abrasive polishing tool, the area of contact between the polishing tool and the semiconductor wafer tends to vary. Because it is difficult to instantaneously change the pressure applied to the semiconductor wafer at the time that the semiconductor wafer is polished, a change in the area of contact between the polishing tool and the semiconductor wafer causes a change in the pressure applied to the semiconductor wafer, failing to keep the amount of material removed from the semiconductor wafer stably. When the semiconductor wafer is positioned across gaps between the segments upon relative movement of the semiconductor wafer and

the polishing tool, a large force is imposed on the semiconductor wafer, tending to polish the semiconductor wafer to an excessively large amount on the edge portion thereof or to produce scratches on the surface of the semiconductor wafer. In order to solve the above drawbacks, the segments of the fixed abrasive are of cyclotomic shapes or sectorial shapes with gaps controlled therebetween, so that the segments can be positioned accurately with relative ease and the fixed abrasive can polish the semiconductor wafer stably. The segment-shaped fixed abrasive is also advantageous in that there is no need for handling a large-sized fixed abrasive which would tend to be damaged when manufactured, and the danger of inclusion of air bubbles into the adhesive layer used to bond the fixed abrasive to the base is comparatively small. The inclusion of air bubbles into the adhesive layer produces a non-bonded area in the layer below the polishing surface to cause the fixed abrasive to be insufficiently fixed to the base. If the fixed abrasive is not sufficiently bonded to the base, then the polishing tool may possibly be separated from the base under frictional forces developed between the polishing tool and the semiconductor wafer being polished, causing damage to the fixed abrasive.

The base, which is of a circular or cylindrical shape, is made of an aluminum alloy or engineering plastics, if the fixed abrasive has a size up to a diameter of about 600 mm. The fixed abrasive assembly thus constructed is sufficiently strong and has a weight that can easily be handled. Generally, a rotatable thick fixed abrasive for use as a polishing tool for polishing 8-inch semiconductor wafers can be manufactured by the above

manufacturing process.

A fixed abrasive for use as a polishing tool for polishing 12-inch semiconductor wafers or larger semiconductor wafers is required to be a size equal to or greater than a diameter of about 700 mm. An assembly including an integrated-type fixed abrasive and base is heavy and cannot easily be handled. If such fixed abrasive assembly is of a split-type structure made up of segments each comprising a base segment and a fixed abrasive segment, then the segments can individually be handled with ease, and a clean room space which is required for replacing the fixed abrasive assembly may be relatively small. For example, cyclotomic or sectorial segments of the fixed abrasive may be fixed to respective segments of the base which are cyclotomic or sectorial in shape except for their attachment areas, and they may be assembled together into a circular or cylindrical assembly on the polishing apparatus. These segments can easily be handled within a clean room without the need for any special apparatus such as a crane, a lifter, or the like.

The various processes for manufacturing the fixed abrasive, e.g., a process of preparing materials, including mixing and dispersing steps of the materials, a granulating process, a forming process, a mounting process of the fixed abrasive on a jig for attachment to the polishing apparatus, and a bonding process of the fixed abrasive to the base, may be carried out in a clean environment, such as a clean room or a clean booth, which is supplied with clean air through a filter. The fixed abrasive thus manufactured is highly clean.

A process of manufacturing the polishing tool according

to the present invention, with attention given to temperatures in the manufacturing steps, will be described below.

In a process of manufacturing a polishing tool which is composed mainly of a resin and is operable to polish a workpiece with abrasive particles by causing the workpiece to be pressed against and brought in sliding contact with the polishing tool, a mixed liquid prepared by mixing a resin, chemical agents, and, if necessary, a slurry, is subjected to a heat treatment, and then a compression molding (compression forming) with heat, thus producing a polishing tool. In this case, the drying temperature of the mixed liquid is lower than the forming temperature (molding temperature) of the polishing tool. As described above, the fixed abrasive is produced by partly or fully drying a liquid in which a slurry, a resin, polishing additives, and forming additives are mixed and dispersed, and pressing the resultant solid material (granulated powder) with heat using a compression forming machine which typically comprises a hot press.

The heat treatment temperature at which the mixed liquid composed of the slurry, the resin, the polishing additives, the forming additives, and the processing additives is dried serves as a parameter which greatly affects the polishing tool. If the heat treatment temperature of the mixed liquid is higher than the forming temperature of the polishing tool, then the interfacial bonding between the solid material particles is weak, leaving interfacial defects in the formed resin. Thus, the formed resin tends to have its interfacial bonding broken. When the interfacial bonding is broken, the abrasive particles are liable to produce large particles during a polishing process, and the

large particles are likely to produce scratches on the surface of the workpiece. In order to eliminate the above shortcoming, the heat treatment temperature of the mixed liquid is made lower than the forming temperature of the dried solid material. With the above temperature setting, the dried solid material can be pressed to shape in the compression forming process at a temperature which is high enough to prevent any interfacial defects from being developed. The fixed abrasive thus formed does not produce large particles during a polishing process, and is prevented from producing large fragments which would be detrimental to the polishing action, thereby preventing scratches from being produced on the workpiece being polished.

In a process of a heat treatment of a mixed liquid composed of a resin, chemical agents, and, if necessary, a slurry, and a compression forming of a dried material to form a polishing tool, the forming temperature of the dried material should preferably be higher than the glass transition temperature of the resin or the dissolution temperature of the resin.

The heat treatment is carried out in the forming process at a temperature equal to or higher than the glass transition temperature (Tg) or the resin dissolving temperature (Tm) to dissolve the resin, thereby bonding the material particles together. In this manner, in the formed resin, the material particles are prevented from being separated. Since no material interfaces are left in the formed resin, but uniform bonding forces are achieved in the formed resin, the abrasive particles are prevented from producing separate material particles or separate material fragments during a polishing process. Consequently,

the abrasive particles are prevented from producing large fragments which would be detrimental to the polishing action, thereby preventing scratches from being formed on the workpiece being polished.

In a process of a heat treatment of a mixed liquid composed of a resin, chemical agents, and, if necessary, a slurry, and a compression forming of a dried material, a resin solvent should preferably be added to the mixed liquid at the time of the heat treatment of the mixed liquid.

By adding a resin solvent at the time of producing the forming material, the solvent acts on the resin to give the resin uniform bonding forces in the forming powder material. If the forming material is produced by a drying process typically using a spray drier, then heat is applied differently within and outside of the forming material particles, resulting in different bonding levels for the resin. However, the added resin solvent dissolves the resin to allow the resin to be uniformly dispersed, thus producing uniform bonding forces for the resin. The added resin solvent also acts to allow the heat treatment of the mixed liquid to be carried out at a lower temperature.

Rather than the heat treatment of the mixed liquid and then the compression forming, the mixed liquid can simultaneously be dried and formed to shape according to a casting process.

In a process of a heat treatment of a mixed liquid composed of a resin, chemical agents, and, if necessary, a slurry, and a compression forming of a dried material, it is preferable to add an organic solvent or a foaming agent to the compression forming material.

The formed polishing tool has material particles which tend to be separated due to the organic solvent or the foaming agent added to the compression forming material. By allowing a resin solvent added to act on the forming material in the compression forming process, the formed resin has no dry powder interfaces, thus producing uniform bonding forces in the polishing tool. The resin solvent may be added not only as a liquid but also as microcapsules. With the heat, the pressure, or the friction between the powder particles at the time of the compression forming, the solvent in the microcapsules is released to act on the forming material. If the solvent is partly left in the formed polishing tool, then the remaining solvent provides a sterilizing effect.

The polymeric material may be in the form of either a powder or a liquid. In order to uniformize the composition ratio of a granulated powder as a forming material and increase the uniformity of the fixed abrasive, it is preferable to use a latex suspension where the polymeric material is uniformly dispersed in a liquid. For use in semiconductor applications, i.e., for polishing semiconductor wafers with reduced metal contamination, the amount of any metals contained in the polymeric material should be as small as possible. The thermoplastic material is generally manufactured by polymerizing many monomers through different processing stages including addition polymerization, copolymerization, condensation polymerization, addition condensation, etc. In those processing stages, water and various agents including polymerization catalysts represented by organometallic compounds and inorgannometallic compounds, polymerization-retarders, dispersing agents, activators,

solvents, catalyst deactivators, stabilizers, emulsifiers, antioxidants, etc are used. The monomers are processed into the polymeric material through a complex process. In order to reduce the amount of metals introduced into the polymeric material of the polishing tool, it is preferable to reduce the metal compounds contained in the chemical agents and water used in the above various polymerization stages. The water and solvents that are used in the polymerization process should preferably comprise pure water or ultrapure water and highly pure solvents, respectively.

Other suitable additives (agents) may be added other than the polymeric material. These additives (agents) include accelerators (KOH, amine, pH adjustors, or the like) including micro (nano) capsule agents, dispersant of abrasive particles such as surface active agent, stabilizers (buffers), mirror-finish improvers (water-soluble macromolecures), polishing additives such as abrasive particle anticoagulants (organic macromolecures), abrasive pariticle self-sharpening regulators (resin solvents), fixed abrasive forming additives, fixed abrasive processing additives (photosensitizers), etc. The amount of metals contained in these additives should also be as small as possible.

The resin solvent may differ from resin to resin to be used. General resins are easily eroded by sulfuric acid, hydrochloric acid 35 %aq, an acid, an alkaline solution, or an organic solvent. For example, in the case of acrylic resins, most organic resins can be used as the resin solvent and, in particular, alcohols and ketones can easily be used as the resin solvent.

A process of manufacturing a fixed abrasive will be described

below with reference to FIGS. 9 through 13A and 13B.

FIG. 9 is a flowchart of a method of manufacturing a polishing tool according to an embodiment of the present invention. In Fig. 9, a manufacturing process of the polishing tool is illustrated in a simplified manner. As shown in Fig. 9, a material of a fixed abrasive is prepared in step 1, and then a forming material is produced in step 2. The forming material is compressed or heat-pressed to produce a formed body (formed resin) in step 3, and then the formed body (formed resin) is fixed to a supporting member in step 4, thus completing a polishing tool in step 5.

Next, a manufacturing process of the fixed abrasive will be described in a concrete manner in detail.

First, a fixed abrasive material powder is manufactured by mixing fine abrasive particles, a polymeric material, and additives. The above materials are mixed with each other, and, if necessary, pure water and a solvent are added to the mixture, thus producing a mixed liquid. The materials are sufficiently dispersed using a stirrer, an ultrasonic dispersing device, or the like. Specifically, a mixed liquid of an abrasive particle powder (or a slurry containing abrasive particles), a resin (a liquid resin, a resin component monomer), and various chemical agents is ultrasonically processed, stirred, and, when necessary, is subjected to various polymerization processes, thereby sufficiently dispersing the above constituents.

FIG. 10 shows an ultrasonic dispersing apparatus for ultrasonically dispersing a mixed liquid. As shown in FIG. 10, a mixed liquid accommodated in a tank 201 is stirred by a stirrer 202, and delivered by a pump 203 to an ultrasonic dispersing

apparatus 205. The ultrasonic dispersing apparatus 205 includes a hard glass flask 206 for storing the mixed liquid supplied from the pump 203, and a container 207 which is ultrasonically vibrated by an ultrasonic wave generator 208 energized by a power supply 209. The container 207 stores pure water for transmitting ultrasonic vibrations generated by the ultrasonic wave generator 208 to the flask 206. The mixed liquid in the flask 206 is ultrasonically vibrated, and then delivered by a pump 210 through a three-way valve 213 to a tank 211. The mixed liquid is stored in the tank 211 after it has been ultrasonically dispersed. In the embodiment shown in FIG. 10, the tank 211 also has a stirrer 212 for stirring the mixed liquid. However, the mixed liquid may be stirred by the stirrer 202 only before the mixed liquid is ultrasonically dispersed. Though two pumps 203, 210 are shown in FIG 10, only one pump may be employed. The mixed liquid which has been ultrasonically dispersed may be directly delivered to a line of a next process without being stored in the tank 211, so that the mixed liquid can be processed in the next process while it is being well dispersed. Each of the pumps 203, 210 used should preferably comprise a tube pump which employs a Teflon (registered trademark) tube for the purpose of contamination control. Similarly, the three-way valve 213 should preferably be made of Teflon (registered trademark).

Then, the mixed liquid is dried by a dryer such as a spray drier into a powder (granulated powder) in which various materials are uniformly mixed. The powder (granulated powder) has a diameter of 0.1 μm to several hundreds μm, preferably an average diameter of about several μm. Alternatively, a mixed powder may

be produced by freeze-drying and then pulverizing, coagulating, and/or precipitating. In the above powder (granulated powder) producing process, the materials may be mixed and then dried, or dried and then mixed, or repeatedly mixed and dried. Depending on the material to be mixed, a material may be directly mixed with a dried powder of other materials.

FIG. 11 shows a process of forming a granulated powder using a spray drier. As shown in FIG. 11, a mixed liquid is stored in a slurry tank 251 (211) having a stirrer and is delivered by a constant-rate supply pump 252 to an atomizer 253. The atomizer 253 sprays the mixed liquid into a container 254. The container 254 is supplied with air which is delivered from a hot air blower 255, heated by an electric heater or a steam heater 256, and filtered by a hot-air filter 257. The mixed liquid is atomized into a mist by the atomizer 253, and the mist is dried into fine particles (granulated into dry particles) by the hot air in the container 254. The produced particles are delivered downwardly to a lower portion of the container 254 where larger particles are trapped by a collecting container 258 connected to the lower portion of the container 254. The remaining particles are carried by air from the container 254 to a centrifugal separator 259 such as a cyclone. In the centrifugal separator 259, the particles are classified, and then trapped and withdrawn from a lower portion of the centrifugal separator 259. The air containing fine particles discharged from the centrifugal separator 259 is supplied to a bag filter 260, where fine particles which have not been removed by the centrifugal separator 259 are removed to make the air clean. Then, the clean air is discharged through

an exhaust fan 261 to the atmosphere. The amount of air drawn by the hot air blower 255 and the amount of air drawn by the exhaust fan 261 are regulated so that the pressure of the interior of the container 254 can be slightly negative pressure. Therefore, the particles trapped by the collecting container 258 are prevented from being scattered, or hot air is prevented from leaking from the connecting portions of the pipes. Further, sphericity of the dried powder can be increased. Thus, the drying operation can be stably performed.

The material powder thus produced may further be classified by a classifier, if necessary.

Next, when necessary, a resin solvent and chemical agent are added to the mixed powder (granulated powder), thus producing a forming material. The forming material is then compressed and heated by a compression forming machine which typically comprises a hot press, thereby producing a fixed abrasive polishing tool. This compression forming may be a heating and compression treatment, a compression treatment, or a casting forming.

A process of heating and compression forming will be described below with reference to FIGS. 12A through 12C. As shown in FIG. 12A, after a lower punch 221 and a die 222 are combined with each other, a forming material powder (a granulated powder dried from a mixed liquid) 223 is placed in the die 222 so as to uniformly fill up the die 222. At this time, a solvent may be added to the forming material powder 223, and a mixture of the forming material powder 223 and the solvent may be sufficiently kneaded and then placed in the die 222. The granulated powder may be mixed with microcapsules 224 containing a solvent therein.

Then, as shown in FIG. 12B, an upper punch 225 is placed on the forming material powder so as not to impose a load to the forming material powder 223, and the forming material powder 223 is heated to a predetermined temperature which is equal to or higher than the softening temperature of the resin. Thereafter, as shown in FIG. 12C, a load is applied to the upper punch 225 to compress the forming material powder 223 into a predetermined volume. At this time, the upper punch 225 may be pressed under positional control. Alternatively, a stopper 226 may be used to allow the upper punch 225 to compress the forming material powder 223 into a predetermined volume. The forming material powder 223 is now compressed into a formed body (formed resin) 223a as a polishing tool.

The die 222 may be vertically movable, and a spacer may be preset beneath the die 222. While the forming material powder 223 is being compressed into the formed body (formed resin) 223a, the spacer may be removed to reduce residual stresses in the compressed formed body 223a. After elapse of a predetermined period of time, the compressed formed body 223a is cooled, and then removed as a polishing tool from the punches and the die.

In the case where the microcapsules 224 containing a solvent therein are used, when the forming material powder 223 is compressed and heated, the outer walls of the microcapsules 224 are broken, allowing the solvent to flow out and act on the particle interfaces of the material powder. The supply of the solvent from the microcapsules 224 may be controlled by a process based on time, temperature, and pressure.

In the process of manufacturing the polishing tool according

to the present invention, the drying temperature of the mixed liquid is lower than the temperature of the compression forming of the forming material. Thus, the generation of large particles which are responsible for scratches formed on the workpiece during a polishing process can be suppressed. The temperature of the compression forming is higher than the glass transition temperature of the resin or the dissolution temperature of the resin. Thus, the material particles of the formed body are prevented from being separated from each other, and the polishing tool having uniform bonding forces can be produced. A resin solvent may be added to the mixed liquid at the time of heat treatment, and an organic solvent or a foaming agent may be added to the forming material before the compression forming.

The formed body (formed resin) is then fixed to a support (base plate) such as a metal plate or a plastic plate by adhesion, fusion, cohesion, or the like, thus completing a polishing tool.

After the formed resin is produced, the shape and surface of the formed resin is worked or finished, thus producing a polishing tool. Because the formed resin is generally not sufficiently strong, and tends to crack or be broken when it is transported or fixed to a machine alone, the formed resin is fastened to a base plate. Though the formed resin may be fixed to the base plate by adhesion, fusion, cohesion, or the like while the forming material is being compressed to shape with heat, it is preferable to fix the formed resin to the base plate after it is compressed to shape with heat if the coefficients of thermal expansion of the formed resin and the base plate are different from each other or the formed resin suffers a material

deterioration. This is because if the coefficients of thermal expansion of the formed resin and the base plate are different from each other, the formed resin tends to be deformed or warped when the formed resin is cooled to a temperature at which the polishing tool is used after the formed resin has been fixed to the base plate at a higher temperature. If the polishing tool is a fixed abrasive polishing tool including abrasive particles, then the formed resin should preferably be thicker for a longer service life. However, if the polishing tool comprises a fixed abrasive which wears a little when it is in use, then the polishing tool may be in the form of a thin flat plate. At any rate, if the fixed abrasive polishing tool is used while water or a liquid is being supplied thereto, then the fixed abrasive tends to swell, and hence the fixed abrasive should preferably be fixed to the base plate in such a state that the fixed abrasive is actually used. Specifically, if a liquid seeps into the fixed abrasive when the fixed abrasive is in use, then the fixed abrasive swells, and hence the fixed abrasive should be kept in a swollen state in advance and then fixed to the base plate. Thereafter, the fixed abrasive should be kept in that state until it is used.

FIGS. 13A and 13B show completed fixed abrasive polishing tools, respectively. FIG. 13A illustrates a polishing tool having a formed body (formed resin) 25 serving as a fixed abrasive or a polishing pad and fixed to a base plate 26. FIG. 13B illustrates a split-type polishing tool composed of a plurality of segments. As shown in FIG. 13B, the split-type polishing tool has a fixed abrasive 25 as a formed resin which is composed of a plurality of separable members 25a, 25b, ···, 25f. Each of

the separable members 25a, 25b, ···, 25f is in the shape of a sectorial segment. These segmental separable members 25a, 25b, ···, 25f are fixed to a base plate 26 by adhesion or the like to provide a uniform polishing surface.

FIGS. 14A through 14E show the manner in which a fixed abrasive polishing tool containing an agent (water-absorbing resin) operates. As shown in FIG. 14A, the fixed abrasive polishing tool has abrasive particles 301 and agent particles 302 which are fixed in place by a binder resin 303. The abrasive particles 301 have pores which are omitted from illustration as the pores have no definite shapes. The agent particles 302 are made of a water-absorbing resin which can swell by absorbing water. As shown in FIG. 14B, when the fixed abrasive polishing tool polishes a semiconductor wafer W, since a cooling medium of water exists between the polishing surface of the fixed abrasive and the semiconductor wafer W, the agent particles 302 absorb the water and are changed into swollen particles 302a. As shown in FIG. 14C, when the abrasive particles 301 are brought into contact with the swollen particles 302a, the swollen particles 302a resiliently bear the abrasive particles 301, thus resiliently polishing the semiconductor wafer W. FIG. 14D shows an agent particle 302 before it swells, and an agent particle 302a after it has swollen by absorbing water. As shown in FIG. 14E, an agent particle 302 may be coated with a water-resistant coating 302c on its surface. The water-resistant coating 302c may be made of wax, but should preferably be made of Teflon (registered trademark), an acrylic resin, or other polymeric material.

Although certain preferred embodiments of the present

invention have been shown and described in detail, it should be understood that various changes and modifications may be made therein without departing from the scope of the appended claims.